Response of hydrological drought to meteorological drought in the eastern Mediterranean Basin of Turkey

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Abstract: The hydrographic eastern Mediterranean Basin of Turkey is a drought sensitive area. The basin is an important agricultural area and it is necessary to determine the extent of extreme regional climatic changes as they occur in this basin. Pearson's correlation coefficient was used to show the correlation between standardized precipitation index (SPI) and standardized streamflow index (SSI) values on different time scales. Data from five meteorological stations and seven stream gauging stations in four sub-basins of the eastern Mediterranean Basin were analyzed over the period from 1967 to 2017. The correlation between SSI and SPI indicated that in response to meteorological drought, hydrological drought experiences a one-year delay then occurs in the following year. This is more evident at all stations from the mid-1990s. The main factor causing hydrological drought is prolonged low precipitation or the presence of a particularly dry year. Results showed that over a long period (12 months), hydrological drought is longer and more severe in the upper part than the lower part of the sub-basins. According to SPI-12 values, an uninterrupted drought period is observed from 2002–2003 to 2008–2009. Results indicated that among the drought events, moderate drought is the most common on all timescales in all sub-basins during the past 51 years. Long-term dry periods with moderate and severe droughts are observed for up to 10 years or more since the late 1990s, especially in the upper part of the sub-basins. As precipitation increases in late autumn and early winter, the stream flow also increases and thus the highest and most positive correlation values (0.26–0.54) are found in January. Correlation values (ranging between –0.11 and –0.01) are weaker and negative in summer and autumn due to low rainfall. This is more evident at all stations in September. The relation between hydrological and meteorological droughts is more evident, with the correlation values above 0.50 on longer timescales (12- and 24-months). The results presented in this study allow an understanding of the characteristics of drought events and are instructive for overcoming drought. This will facilitate the development of strategies for the appropriate management of water resources in the eastern Mediterranean Basin, which has a high agricultural potential.

Keywords: meteorological drought; hydrological drought; standardized precipitation index (SPI); standardized streamflow index (SSI); eastern Mediterranean Basin

1 Introduction

Complex environmental events that have a significant effect on agriculture, society, and

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ecosystems attract attention as large-scale droughts (Nkiaka et al., 2017). Wilhite and Glantz (1985) defined drought as insufficient rainfall for a long period of time and divided it into four main categories (meteorological, agricultural, hydrological, and socio-economic). The last report from the International Panel on Climate Change (IPPC, 2013) declared the Mediterranean as one of the most sensitive regions in the world susceptible to the impacts of global warming. The part of Europe that will be most affected by drought is the Mediterranean Basin, including Turkey, due to climate change (IPCC, 2007). Estimates show that 0.5×10^6 people are likely to see increased water resource stress by 2020 as a result of climate change (Aerts and Droogers, 2004). It is expected that population growth and increasing urbanization, especially in the coastal regions of the eastern and southern Mediterranean countries, will lead to both high water demand and further deterioration of water quality (MedECC, 2019). Bordi et al. (2009) also pointed out that the area where drought events took place in Europe increased in the latter 50 years of the 20th century. An increase in drought based on decreasing precipitation in many countries within the Mediterranean Basin, such as Greece, southern Italy and Turkey, has been proven correct (Kömüşçü et al., 2004; Sönmez et al., 2005; Livada and Assimakopoulos, 2007; Mendicino et al., 2008; Giannakopoulos et al., 2011; Caloiero et al., 2018). Drought trends are expected to progressively cause more damage until the end of the 21st century, as well as lead to different results in drought frequency, duration and severity (Spinoni et al., 2018).

A study on the relative contribution of changes in precipitation versus evaporative demand pointed out that the expansion of dry areas in the 21st century has been attributed to a widespread increase in potential evapotranspiration (Cook et al., 2014). Extreme climatic events such as the increase in the number of very heavy rainy days and extreme rainfall events are predicted to inevitably affect the southern, central, and southwestern regions of China and Turkmenistan (Duan et al., 2016, 2019a, b). The report of the IPCC (2007) states that significant decreases will occur in precipitation with the increase in temperatures toward the end of the 21st century. The magnitude and frequency of hydro-meteorological extremes such as heavy rainfall, flash floods, strong winds, storm surges, forest fires, and droughts accompanied by heat waves could significantly affect the ongoing climate in the Mediterranean region (Ducrocq and Gaume, 2016). These conditions will be reflected mostly in the budget of streams as a negative decrease (Şen et al., 2013). Especially in the summer half-year (i.e., April to September), a reduction in precipitation is becoming more severe in Mediterranean countries and as a consequence, evapotranspiration rates are likely to be higher, leading to a decrease in streamflow (Schneider et al., 2013). In addition, it is expected that streamflow droughts will become more severe and create an increase in drought in the Mediterranean and Alpine regions because of the contribution of reduced snow melt (Andreas et al., 2018). Studies conducted in recent years predict that climate change, extreme wet events and human activities will cause adverse effects on water quality and water resources in Asian countries (Sun et al., 2015; Duan and Takara, 2020).

Due to the increase in average temperature worldwide, expansion of the high-pressure band around the 30° latitude towards the poles is the most important result of climate change (Quan et al., 2004; Frierson et al., 2007; Seidel et al., 2008; Johanson and Fu, 2009). The magnitude of the expansion has increased in the last 30–40 years (Grise and Davis, 2020). Warming of the Mediterranean Sea surface, spreading down to deeper layers, has been indicated by both global and regional climate models, which will influence the exchange of water and heat in the Strait of Gibraltar and the heat and salinity in deep layers of the North Atlantic Ocean (Ducrocq, 2016).

The central, southern and southeastern regions of Turkey are under the effect of a semi-arid climate and are faced with the risk of desertification (Türkeş, 2005; Türkeş and Tatlı, 2009; Bayer Altın et al., 2012; Bayer Altın and Barak, 2017; Bayer Altın and Altın, 2018). Climate change will further increase its impact in the near future, which will transform the southern half of Turkey into a climate similar to that of its southern neighbors, Syria and Iraq. The central and humid northern regions will face an arid climate that currently prevails in the southern regions. For Turkey, this means that the risk of drought and desertification will increase in all regions (Şahin and Kurnaz, 2014).

Studies on the effect of low precipitation on streamflow and its correlation with the eastern

Mediterranean Basin are limited. The majority of studies are related to meteorological drought analysis using the standardized precipitation index (SPI) and only based on the precipitation data of basins in the Mediterranean region of Turkey (Bahadır, 2011; Keskiner et al., 2016; Topçu, and Seçkin, 2016; Oğuz et al., 2017; Çelik and Gülersoy, 2018; Çuhadar and Atış, 2019). An annual precipitation decreased by 157 mm (25%) and an annual runoff decreased by 118 mm (52%) were detected in a study on the potential future (2070s) impacts of climate change on the hydrology and water resources of the Seyhan River Basin (Fujihara et al.,2008). Study of Gümüş and Algın (2017) was the first related to hydro-climatological drought analysis of the Seyhan and Ceyhan river basins in the southern region of Turkey. The drought conditions of these basins located east of the eastern Mediterranean Basin and sharing the same climatic conditions were determined using the streamflow drought index (SDI) (Bayer Altın et al., 2020). Dabanlı (2018) investigated the drought hazard and vulnerability based on hydro-meteorological and actual socioeconomic data for Turkey.

Previous studies (e.g., Sönmez et al., 2005; Türkeş and Tatlı, 2009; Kurnaz, 2014) have examined only either meteorological drought or hydrological drought (Bayer Altın et al., 2020). The difference of the current study from previous studies (e.g., Bayer Altın et al., 2020) is the evaluation of meteorological drought together with hydrological drought. Another feature that makes this study different is time and space (the eastern Mediterranean Basin). Thus, the meteorological and hydrological drought values of the eastern Mediterranean Basin were compared and the accuracy of the predictions was discussed.

The present study is the first to provide comprehensive drought analysis by taking into account the data of streamflow and precipitation obtained from the sub-basins of the eastern Mediterranean Basin. This study has two main objectives: (1) to investigate the causes of drought in the eastern Mediterranean Basin in the light of hydrological and meteorological data; and (2) to determine the hydrological drought in the sub-basins on short and long timescales. In addition, it focuses on the characteristics of propagation from meteorological to hydrological drought. Accordingly, based on the meteorological and hydrological conditions examined spatially throughout the basin, this paper presents temporal variations of drought severity on 3-, 6-, 9- and 12-month timescales.

2 Study area

The eastern Mediterranean Basin is one of 25 hydrological river basins in Turkey. In the south of Turkey (Fig. 1a), the basin area includes the water collection areas of the rivers between the Sedir River in the west and the Tarsus River in the east (Fig. 1b). In other words, the basin covers the area that discharges the water of the Göksu River and other rivers into the Mediterranean. The elevation of the eastern Mediterranean Basin varies between 0 and 2000 m a.s.l. and exceeds 3000 m a.s.l. on its ridges and peaks. It is bordered by the Ak Mountain in the west, the Taurus Mountains in the north, the Bolkar Mountains in the east, and the Mediterranean in the south. The basin, with an area of 2.18×10^4 km^2, is located within the geographical co-ordinates 36°00′–37°28′N and 32°06′–35°09′E (GDWM, 2016). Except for the Göksu and Tarsus (Berdan), the rivers are short and the beds are inclined. The basin lies completely within the Adana sub-region of the Mediterranean region. The location of the stream gauging stations (SGSs) and meteorological stations, with their geographical properties, is shown in Figure 1b and Tables 1 and 2.

In the study, stream-gauging data were obtained from the Göksu, Efrenk, Pamuk and Lamas rivers. The most important river of the basin is Göksu. Its two tributaries originate from the Middle Taurus Mountains. It is named Göksu after its two tributaries, which merge to the south of Mut District. Göksu River, which is approximately 260 km long, flows south from its headwaters in the Taurus Mountains to the Mediterranean via a delta between Taşucu and Silifke. Another important water source is the Lamas River, approximately 130 km long, which collects the water between the Mount Sakaryayla and Güzeloluk (GDWM, 2016). Efrenk River (Müftü Creek) originates from the southern slopes of the Bolkar Mountains. It is 100 km long and turns south in the Çağ vicinity and flows into the sea through the city of Mersin. Cehennem River, one of the

tributaries of the Tarsus River, takes the name of Pamuk River while passing the city of Çamlıyayla. The river called Keşbükü in the Keşbükü gorge merges with the Kadincik River near the Çevreli village before arriving at the Muhat Bridge (GDWM, 2016).

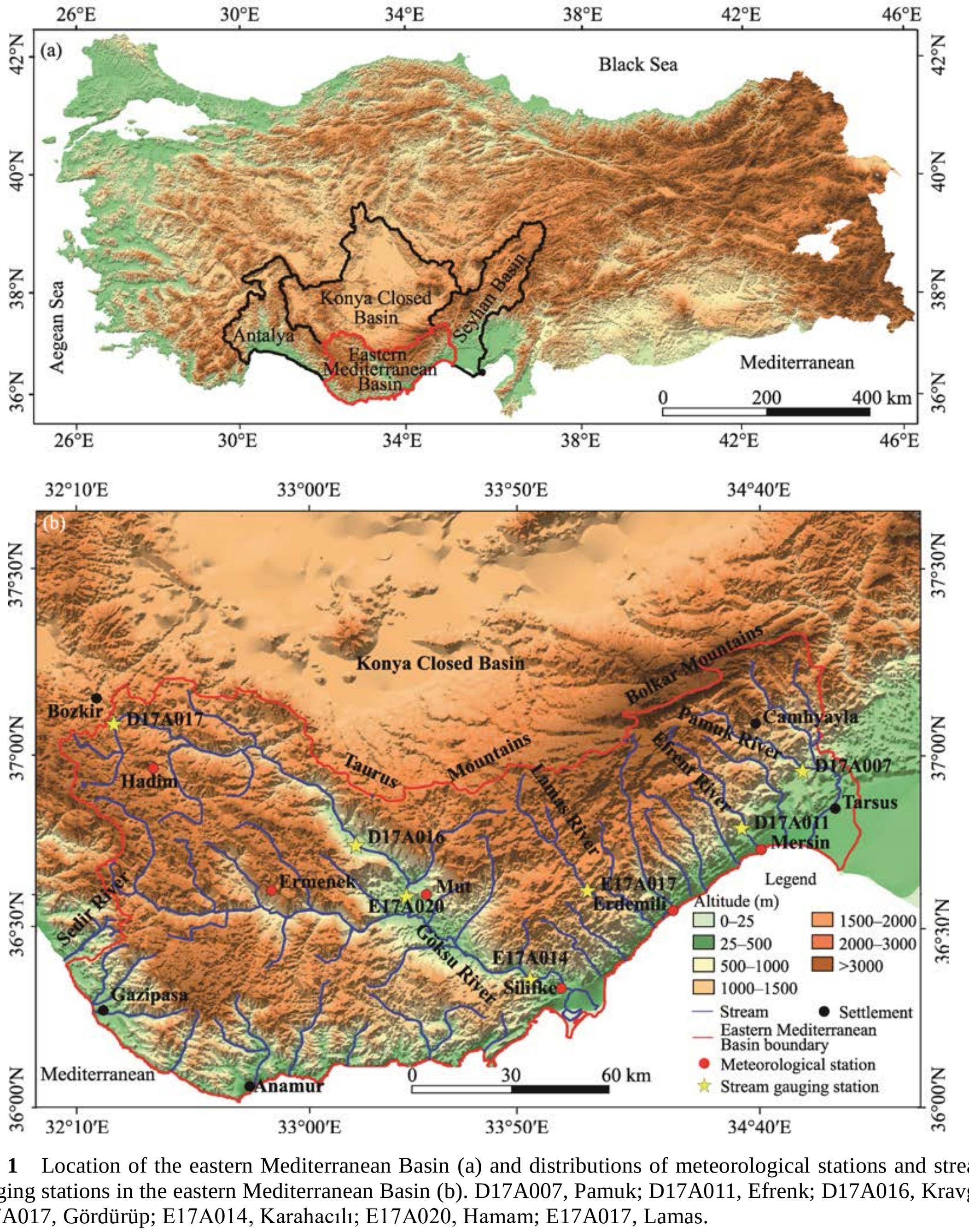

Fig. 1 Location of the eastern Mediterranean Basin (a) and distributions of meteorological stations and stream gauging stations in the eastern Mediterranean Basin (b). D17A007, Pamuk; D17A011, Efrenk; D17A016, Kravga; D17A017, Gördürüp; E17A014, Karahacılı; E17A020, Hamam; E17A017, Lamas.

Surface flow in the basin is high due to steep slopes, sparse forest cover and high precipitation; therefore, river regimes are irregular (Topraksu, 1974). The length of the eastern Mediterranean Basin, whose total rainfall area is 2.18×10^4 km^2, is 129 km. Average annual precipitation was 745 mm and average annual streamflow was 11.07 km^3/a for the period 1980–2016 (FDMD, 2018). Agricultural lands in the eastern Mediterranean Basin occupy 4.96×10^5 hm^2 and constitute 22.7% of the basin (GDWM, 2016). Dams and ponds on the Tarsus, Anamur, Göksu and Lamas rivers, which are surface water sources, are used for agricultural irrigation and the supply of drinking

water. Almost all of the rivers examined feed these dams and ponds.

The basin is generally under the influence of the Mediterranean climate. A typical Mediterranean climate is observed along the coast; summers are hot and dry, transitional seasons are clear, and winters are cool and rainy. However, on approaching the Central Anatolia Region (e.g., Ermenek and Hadım) and toward mountainous areas, the effects of the continental climate and mountain climate on the Mediterranean climate can be felt (Arınç, 2019).

Table 1 Geographical properties, observation and analyzed periods for the stream gauging stations

Stream gauging station code	River/ station name	Period	Elevation (m)	Basin area (km²)	Latitude	Longitude
D17A017	Göksu/Gördürüp	1967–2017	1241	364	37°06′49″N	32°18′27″E
D17A016	Göksu/Kravga	1967–2017	233	2994	36°46′54″N	33°11′15″E
E17A020	Göksu/Hamam	1967–2017	127	4304	36°38′09″N	33°22′10″E
E17A014	Göksu/Karahacılı	1967–2017	24	10,065	36°24′13″N	33°48′56″E
D17A011	Efrenk	1967–2017	125	410	36°51′42″N	34°33′11″E
D17A007	Pamuk	1967–2017	132	599	37°01′50″N	34°46′06″E
E17A017	Lamas	1967–2017	975	1005	36°45′43″N	33°54′58″E

Table 2 Geographical properties, location, observation and analyzed periods for the meteorological stations

Station name	Sub-basin station	Period	Elevation (m)	Annual precipitation (mm)	Latitude	Longitude
Hadim	Göksu	1967–2017	1461	646	36°59′09″N	32°27′21″E
Mut	Göksu	1967–2017	340	402	36°38′42″N	33°26′13″E
Mersin	Efrenk	1967–2017	5	587	36°48′43″N	34°38′28″E
Erdemli	Alata	1967–2017	10	526	36°36′20″N	34°18′36″E
Silifke	Göksu	1967–2017	30	556	36°22′33″N	33°55′28″E

3 Methods

A period of 51 years (1967–2017) was used for the calculation of indices such as standardized streamflow index (SSI) and SPI. The 1967–2017 reference period based on available hydrological and meteorological records was assessed in the present study. The main advantage of SSI is that it enables us to determine the onset and end of a drought as well as the temporal relations of the hydrological conditions of a river or a set of streams. Months with drought events calculated by the SSI method were assessed in five categories (Table 3) for the seven SGSs operated by the General Directorate of State Hydraulic Works (Turkish acronym: DSI). These SGSs are found in the Göksu, Pamuk, Efrenk and Lamas sub-basins of the eastern Mediterranean Basin. In addition, SGSs located behind dams were specifically chosen.

Table 3 Classification scale for standardized streamflow index (SSI) and standardized precipitation index (SPI) values (McKee et al., 1993)

State	Description	Criterion
0	Non-drought	SPI, SSI≥0.0
1	Mild drought	–1.0≤SPI, SSI<0.0
2	Moderate drought	–1.5≤SPI, SSI< –1.0
3	Severe drought	–2.0≤SPI, SSI< –1.5
4	Extreme drought	SPI, SSI≤ –2.0

The five meteorological stations are Hadim located in the upper section of the sub-basin, Mut in the middle section of the sub-basin, and Mersin, Silifke and Erdemli in the lower section of the sub-basins (see Fig. 1b). Four SGSs are found in the Göksu River sub-basin at Gördürüp (D17A017), Kravga (D17A016), Hamam (E17A020) and Karahacılı (E17A014). Two SGSs

(Kravga and Hamam) are found in the middle part. Gördürüp and Karahacılı SGSs are found in the upper part and lower part of the sub-basin, respectively. Efrenk (D17A011), Pamuk (D17A007) and Lamas (E17A017) are found in the lower part of the sub-basin with the same name.

SSI was developed by Shukla and Wood (2008) on the basis of SPI (McKee et al., 1993, 1995) to determine the effect of drought on water flow. The SSI and SPI are defined as follows:

$$\mathrm{SSI} = x_i - x_j \,/\, \sigma, \tag{1}$$

$$\mathrm{SPI} = x_i - x_m \,/\, \sigma, \tag{2}$$

where x_i for SSI (m^3/s) and x_i for SPI (mm) are the streamflow and precipitation in a reference period of time, respectively; x_j (m^3/s) and x_m (mm) are the mean streamflow and mean precipitation, respectively; and σ is the standard deviation. The same approach was used for precipitation values in sub-basins where SGSs are located, resulting in the SPI. Its calculation is similar to SSI, and therefore SPI has the same features of simplicity and effectiveness. This allows a comparison of meteorological and hydrological variables. Negative SPI and SSI values point to a potential deficit of precipitation and streamflow, respectively. In a drought assessment based on SPI and SSI values, the period with negative values is defined as a meteorological and hydrological dry period, respectively. The month when the indices fall below zero is considered as the beginning of the drought, and the month when the indices rise to positive values is considered as the end of the drought. In other words, a dry period for a certain time-scale can be determined from the SPI and SSI value sequences by finding the first value lower than –1.

In order to calculate the SPI values on different timescales, we firstly obtained the cumulative sum of precipitation amounts over multiple timescales (3, 6, 9, 12 and 24 months). The same method was applied to streamflow data for SSI. SPI and SSI were computed on four different and multiple timescales, for example, 3-month (October–December is identified as a short timescale with the acronyms of SPI-3, SSI-3 and Oct–Dec), 6-month (October–March is identified as a medium timescale with the acronyms of SPI-6, SSI-6 and Oct–Mar), 9-month (October–June is identified as a long timescale with the acronyms of SPI-9, SSI-9 and Oct–Jun) and 12-month (October–September is identified as a long timescale with the acronyms of SPI-12, SSI-12 and Oct–Sep) timescales. In addition, the data included in the SPI-24 (2 years SPI) and SSI-24 (2 years SSI) are thus based on monthly precipitation and streamflow input data from 1967 until 2017.

The relationship between SPI and SSI is understood through Pearson's correlation coefficient (*r*). We calculated this correlation in two ways according to the different timescales, such as 1-, 3-, 6-, 9-, 12- and 24-month by taking into account the sequential months in a year. If the *r* values are between 0.7 and 1.0, 0.3 and 0.7, or 0.0 and 0.3, there are the strong, moderate and weak correlations, respectively. If the *r* value is equal to zero, it indicates no correlation (Ratner, 2009).

4 Results and discussion

4.1 SPI and SSI temporal variations of drought

In this study, we calculated SPI and SSI values based on meteorological and hydrological data from the eastern Mediterranean Basin for the 3-, 6-, 9- and 12-month timescales. The distributions of SPI and SSI on different timescales are shown in Figures 2 and 3. Although the climatic conditions of the sub-basins in which the gauging stations are located differ little from each other; SSI and SPI values calculated by months appear quite consistent, as shown in Figures 2 and 3. Since the topographic features, air mass and precipitation data of these basins are quite similar; they are assessed together in terms of SPI and SSI values. The moderate drought threshold (–1.0) of SPI and SSI classes (Table 3) is also provided in Figures 2 and 3. Moreover, the threshold between –1.0 and 0.0 demonstrates the early stage of drought (Figs. 2 and 3). As shown in Figure 2, the value below the threshold of –1.0 indicates periods where the indices SPI and SSI are between moderate drought and extreme drought. It is possible to identify the probability of encountering moderate dry conditions on the scales of 3 and 6 months.

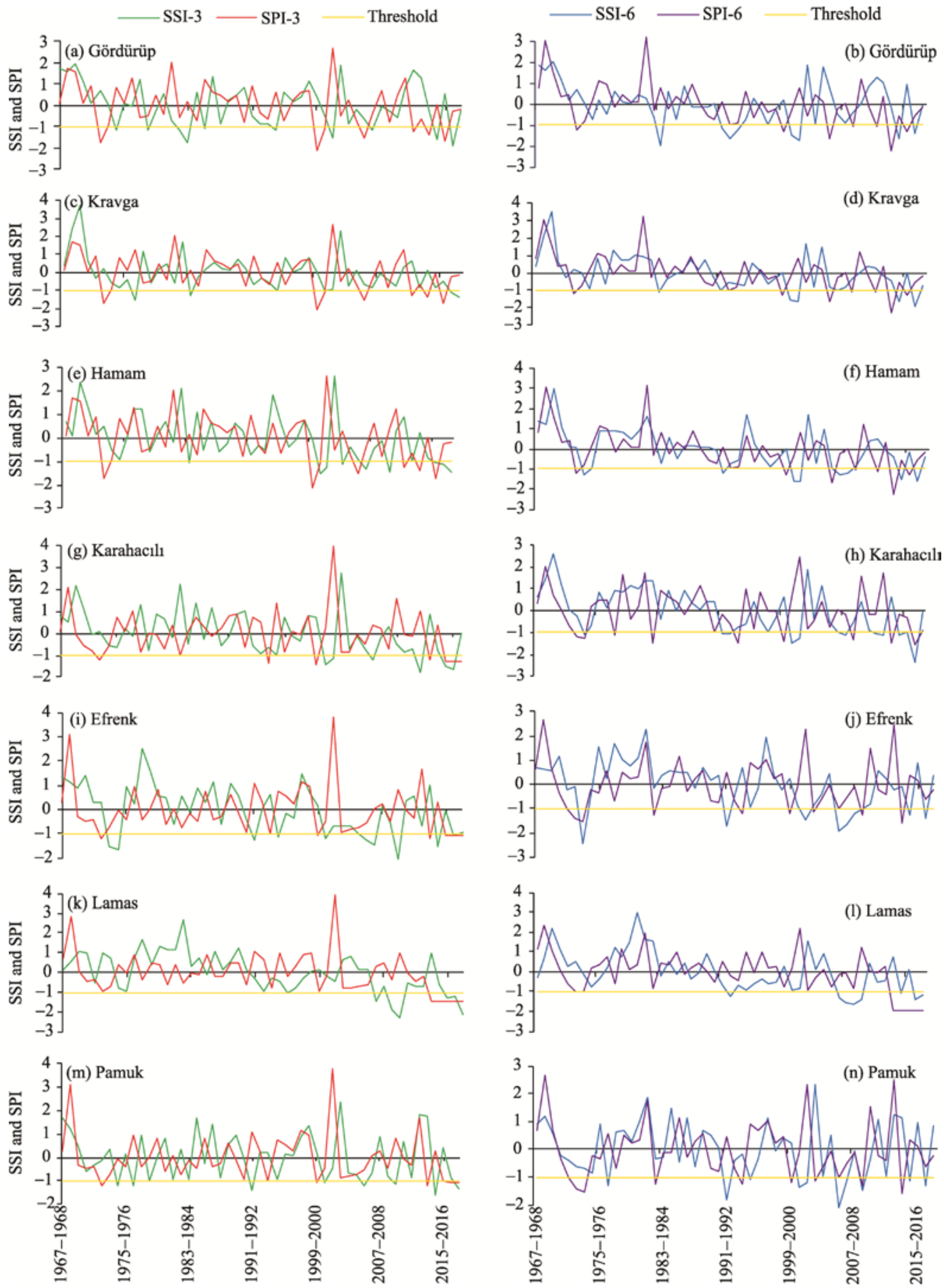

Fig. 2 Standardized streamflow index (SSI) and standardized precipitation index (SPI) series at seven stream gauging stations for time scales of 3 (Oct–Dec; a, c, e, g, i, k, m) and 6 (Oct–Mar; b, d, f, h, j, l, n) months from 1967 to 2017

Mild to extreme drought events for SSI-3 and SPI-3 occur in general at all gauging stations after 1990–1991 and 1991–1992, respectively, except at Lamas. Drought events are encountered at Lamas after 2002–2003. The variation in SPI values shows that extreme drought events (SPI value of –2.1) are determined only in 1999–2000 for SPI-3 at Gördürüp, Kravga and Hamam stations (Fig. 2a, c, and e), but extreme drought events for SSI-3 are not observed in this year. A moderate drought event occurs in the following year (2000–2001) at these stations with an SSI

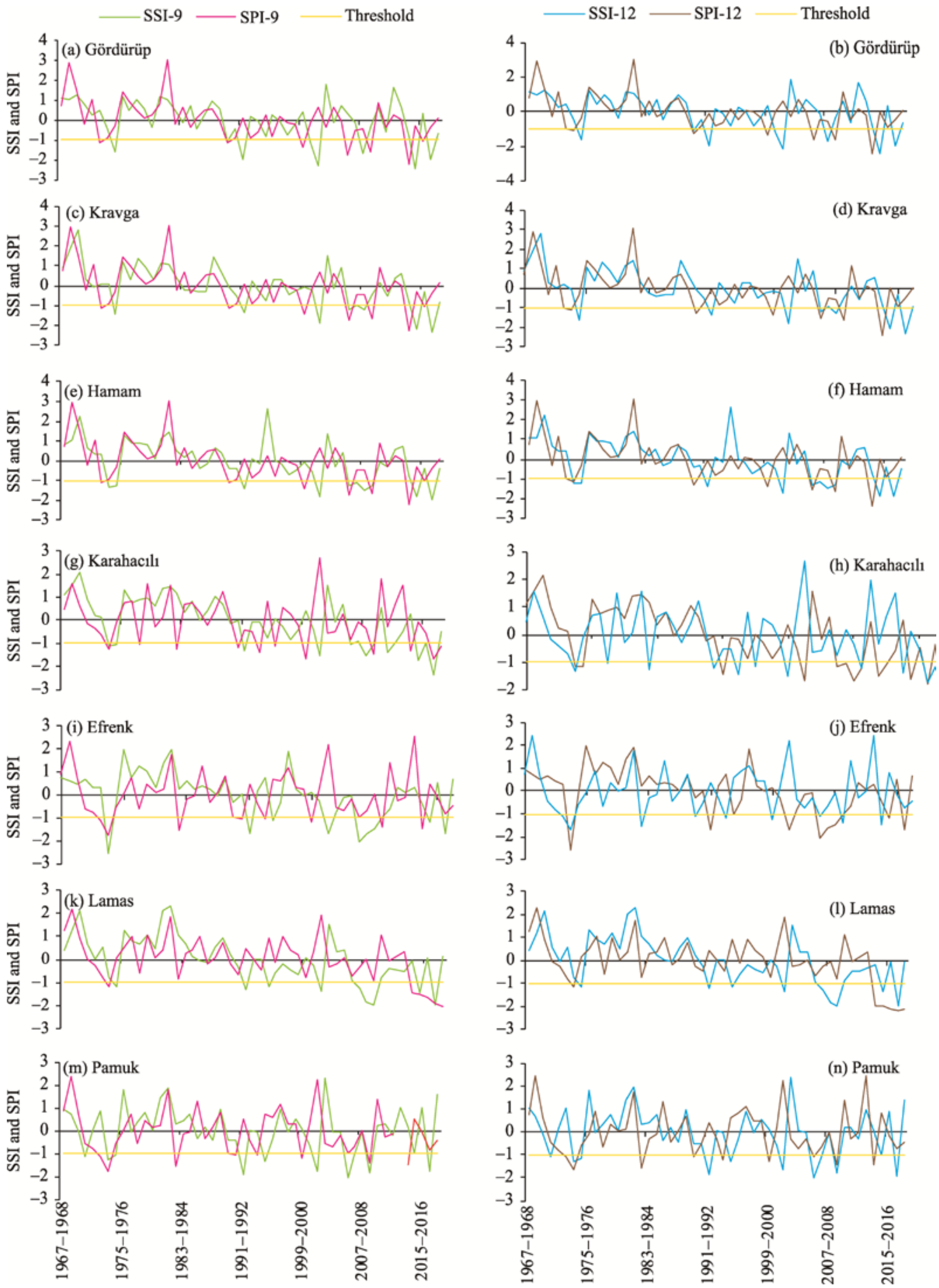

Fig. 3 SSI and SPI series at seven stream gauging stations for time scales of 9 (Oct–Jun; a, c, e, g, i, k, m) and 12 (Oct–Sep, annual; b, d, f, h, j, l, n) months from 1967 to 2017

value ranging between –1.6 and –0.5. A similar situation is encountered at Karahacılı station (Fig. 2g). Moderate and mild drought events for SPI-3 (values of –1.4 and –0.1, respectively) are noted at Karahacılı station in 1999–2000 and 2011–2012, respectively. The same drought event is observed at this station with SSI values of –1.4 and –1.8 in 2000–2001 and 2012–2013, respectively. The mild drought observed in 2008–2009 for SPI-3 at Efrenk and Lamas stations is an extreme drought for SSI-3 in the following year (Fig. 2i and k); however, the moderate drought

observed in 2013–2014 for SPI-3 at Pamuk station causes only a moderate drought for SSI-3 in the following year (Fig. 2m).

Drought events for SPI-6 are observed from the year 1990–1991 at all stations, while drought events for SSI-6 are observed in the following year, namely, 1991–1992. However, an exception, for the beginning of drought events for SPI-6 at Efrenk and Pamuk stations, is 1984–1985. The variation in SPI-6, SPI-9 and SPI-12 values shows that an extreme drought event (SPI value below –2.0) is determined only in 2013–2014 at Gördürüp, Kravga and Hamam stations (Figs. 2 and 3). However, the extreme drought events for SSI-6, SSI-9, and SSI-12 are not observed in this year but the following year, namely, 2014–2015. SSI values vary from –1.9 to –1.1 in 2014–2015.

The variation of SPI-6, SPI-9 and SPI-12 values shows that a severe drought event (–2.0<SPI< –1.5) is observed in 2013–2014 at Karahacılı, Lamas, Efrenk and Pamuk stations. SSI-6, SSI-9 and SSI-12 of these stations vary from –1.8 to –1.1 in 2014–2015. Accordingly, extreme and severe values of SPI for all timescales emerge as severe and moderate hydrological drought in the following year after the end of 1990.

Mild drought and wet conditions for SSI-3, SSI-6, SPI-3, and SSI-6 frequently follow each other from the beginning of the 1970s to the mid-1980s (Fig. 2a–n). The longest wet duration for SSI-9, SSI-12, SPI-9, and SPI-12 is observed in general as a 17-year period initiated from 1973 at all stations (Fig. 3a–n). Severe and extreme drought events for SSI are observed on 6-, 9- and 12-month timescales at all stations in 2016–2017. The SSI values vary from –2.4 to –1.1. The year 2001–2002 is the period of moderate to severe drought on these timescales. The year of 2014–2015 for SSI experiences drought on all timescales and at all stations, but only mild and moderate drought events are dominant. The year in which mild and moderate drought events dominated for SPI on all timescales is 1999–2000. Moderate and severe drought events for SPI are observed in 2013–2014 at all stations.

In general, mild drought events are observed mostly for SSI-3 and SPI-3, even in the driest years. Although an extreme wet event is observed in 1981–1982 at some stations in respect of SPI values, extreme wet conditions for SSI are not observed at all stations. Another extreme wet event for SPI is observed in 2001–2002 at some stations, and extreme wet conditions for SSI are observed in the following year, i.e., 2002–2003. Accordingly, in all the short and medium terms (3 and 6 months) and long terms (9 and 12 months), the values of SPI and SSI further fluctuate under the influence of each new precipitation and streamflow measurement, because each new drought event has a greater effect on the cumulative totals. This is more prominent for SPI-12 and SSI-12 values from 1994. According to SPI-12 values obtained from 1994 to 2017 (a duration of 23 years), severe and extreme drought events are frequently observed since the late 1990s at all stations (except Lamas station). An uninterrupted drought period is observed from 2002–2003 to 2008–2009.

When the results of SPI are examined, it is seen that they parallel findings obtained from previous studies. Akbaş (2014) reported the presence of large areas with excessive humidity in the Mediterranean region of Turkey in July 1992, which is a dry month in terms of precipitation climatology for the period 1929–2009. Again, in this study, drought events were identified in February 1991, which is known to be a humid period in the Mediterranean region, and also in 2001 in the whole of Turkey. In a study on the impact of drought on agriculture for 2007–2008, the mean of total precipitation country-wide during the 2007–2008 agricultural year was 596 mm; this means an 8.6% decrease in total precipitation with regard to the norm, which created significant problems in food supply for wheat, maize and rice production in 2007 (Şimşek and Çakmak, 2010), and was supported by Akbaş (2014).

In a study to investigate the spatial and temporal dimensions of meteorological drought for the period 1930–2002 in Turkey, it was detected that in general, as the timescale increases, the frequency of severe droughts increases, especially on the Mediterranean coast and in some areas of Central Turkey (Sönmez et al., 2005). This result determined for the inner regions is confirmed by Bayer Altın (2019a, b). In these studies, the hydrological drought was determined by the SDI index. The SDI of the Konya Closed Basin (located in Central Anatolia region) and SPI of the KOP (Konya Plains Project) region (including 8 provinces covering 63% of the Central Anatolian

region and 12% of Turkey) were examined. In both drought analyses, severe and extreme droughts in the annual SPI were detected for the period 1950–2018, and 2013 and 2014 were determined to be the driest years of the last 10 years. In addition, according to the SDI findings, the periods with the highest number of dry years are SDI-9 and SDI-12. These are also the periods when severe and extreme drought events were experienced from 2001 to 2014 in all sub-basins of the Konya Closed Basin (Bayer Altın 2019a). The same findings for SPI-12 in the period 2002–2008 were detected by Gümüş and Algın (2017) for the period 1965–2010 in the Seyhan and Ceyhan river basins, and by Cook et al. (2016) for 900 years (1100–2012) in the Mediterranean Basin. In our study, an extreme meteorological drought is not observed as a hydrological drought in the same time period in the same year but a hydrological drought is observed in the following year. It is apparent that the effect of meteorological drought on hydrological drought occurs one year later. The desynchronization of the two indices accords with the findings for the Seyhan and Ceyhan river basins (Gümüş and Algın, 2017).

The percentages of drought events on different timescales based on SPI and SSI are shown in Figure 4. Both SSI and SPI consistently show moderate droughts as the most common occurrence in the basin during the past 51 years, regardless of all timescales. Results of the SSI analyses indicated that four stations (Gördürüp, Kravga, Hamam and Karahacılı) show a percentage of drought years above 50% for the 3-month timescale (Fig. 4a). The highest percentage number of mild and moderate drought events is detected at Karahacılı station with 49% and 55%, respectively. The longest drought duration appears to start from 2002–2003 and lasted for 14 years at this station, with exceptions of 2008–2009 and 2013–2014 (see Fig. 2g). The lowest SSI value is –1.8 in 2012–2013, indicating a severe drought event.

Results of the SPI analyses indicate that four stations (Pamuk, Efrenk, Lamas and Karahacılı) show a percentage of drought years above 50%, and three stations (Gördürüp, Karvga and Hamam) show nearly 50% for the 3-month timescale (Fig. 4b). Drought occurs in more than half of the 6-month timescales for SSI-6 at Karahacılı (51%), Lamas (55%) and Pamuk (53%) stations. Drought events emerge as being below 50% at other stations on this timescale. More than half of the 6-month timescales for SPI-6 experience drought at all stations, except for Lamas station. Those stations in which drought occurs below 50% on the 9-month timescale for SSI-9 are Gördürüp (47%), Karahacılı (49%), Lamas (47%) and Efrenk (41%). Drought occurs above 50% on the 9-month timescale for SSI-9 at Kravga, Hamam and Pamuk stations. At below 50% of the 9-month timescale for SPI-9, drought occurs only at Lamas station (43%). The proportion of drought having the lowest percentage for SSI-12 is observed at Efrenk station, covering approximately 39% of the 12-month timescale. A similar condition coincides with the percentage of SPI-12 for the 12-month timescale at Lamas station, with drought years occupying 49%. Drought occurs at more than 50% of the 12-month timescale for SPI-12 at other stations.

Figure 4c–i shows the percentage of drought events based on SSI and SPI indices with different timescales in the sub-basins. Both SSI and SPI indices consistently indicate moderate droughts as occurring the most in the sub-basins during the past 51 years, irrespective of timescales. This is followed by mild drought in all the sub-basins. Although moderate drought conditions are observed at all stations, the highest percentage of this drought event for SSI-3 is detected at Hamam and Karahacılı stations, with the value above 50%. The percentage of moderate drought events for SPI-3 is below 50% at Hamam station and 53% at Karahacılı station.

The highest percentage of moderate drought events for SSI-6 is detected at Lamas, Efrenk and Pamuk stations, with the value above 50%. The percentage of moderate drought events for SPI-6 is below 40% at Lamas and Efrenk stations and below 50% at Pamuk station. The percentage of moderate drought for SSI at Karahacılı station varies from 41% to 49% on the 6-, 9- and 12-month timescales. The percentage of moderate drought for SPI at Karahacılı station is just above 50% on the 9-month timescale. The percentage of moderate drought for SSI at Karahacılı station is only above 40% on the 6-month timescale and below 40% on the other timescales at Gördürüp station. The percentage of moderate drought for SPI at Gördürüp station is below 40% on the 6-, 9- and 12-month timescales at Gördürüp station. The percentage of moderate drought for SPI and SSI at Hamam and Kravga stations varies from 41% to 47% on the 6-, 9- and 12-month timescales. The percentage of moderate drought for SPI at Efrenk station is above 50%

on the 12-month timescale. To the contrary, the lowest percentage of moderate drought events for SSI-12 is detected at Efrenk station, with the value above 25%. A similar situation for this timescale is found at Pamuk station, with the value of 35%. At other stations, the percentage of moderate drought for SPI and SSI shows close values in the long-term period (12-month), with the values between 35% and 49% for SSI and between 39% and 49% for SPI. Based on the distribution of SSI-12 index values in the sub-basins, the lower part of the sub-basins is notable for being where the total duration of droughts is shortest, at below 45% of the total 12-month timescale, while the middle and upper part of the sub-basins are identified as where droughts evidently lasted longer, above 45% of the 12-month timescale.

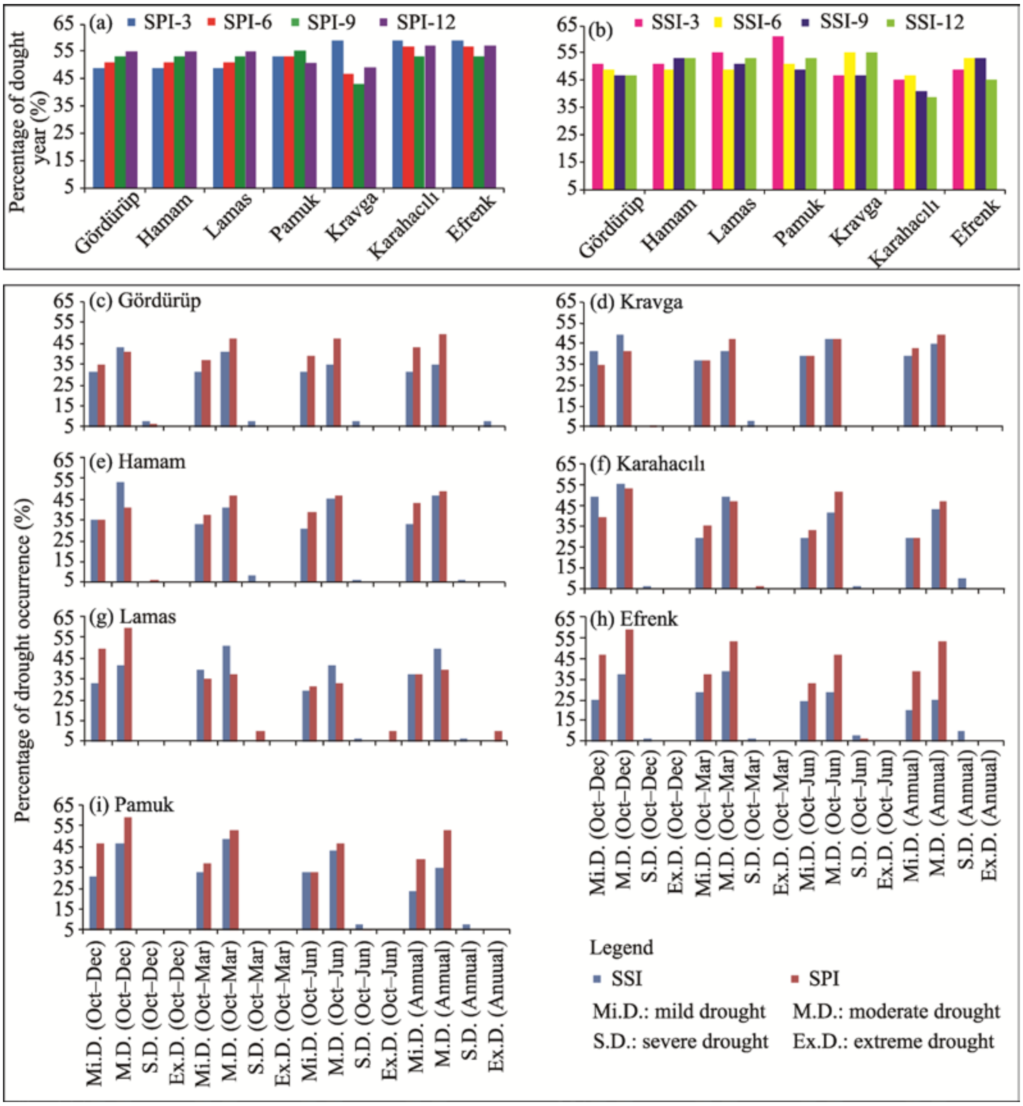

Fig. 4 Percentage of drought year in SPI series (a) and SSI series (b) in different sub-basins of the eastern Mediterranean Basin on different time scales (3-, 6-, 9-, and 12-month) from 1967 to 2017, as well as percentage of drought occurrence in different sub-basins in SPI and SSI series (c–i)

Severe drought for all timescales and the SSI index is observed at all stations. On all timescales of severe drought conditions, the most prominent stations are Efrenk and Karahacılı. In 10% of the 12 months, severe drought occurs at these stations. About 6% of the 3-month and 6-month periods and 8% of the 9-month period experience severe drought at Efrenk station. At Karahacılı station, severe drought occurs in 8% of the 3-, 6- and 9-month periods and 4% of the 12-month

period. Approximately 8% of the 6-month period experiences severe drought; this portion varies from 2% to 6% at Kravga and Hamam stations. There is no extreme drought at Hamam station for any timescale. At Gördürüp station, 8% of the 12-month period and 4% of the 9-month period have extreme drought, while at Kravga station, 4% of the 12-month period and 4% of the 9-month period experience extreme drought. Extreme drought occurs at Karahacılı station in only 2% of the 6 and 9 months. At Lamas station, extreme drought is observed for 4% of the 6 months. Concerning Efrenk station, 2% of the 3 and 6 months and 4% of the 9 and 12 months have extreme drought. In the case of Pamuk station, 2% of the 6, 9 and 12 months experience extreme drought. In general, when the duration is longer, the number of severe and extreme drought events increases in all sub-basins.

Severe and extreme drought for all timescales and the SPI index is observed at three stations, namely, Gördürüp, Kravga and Hamam. The percentage of severe and extreme drought varies from 2% to 6% at these stations on all timescales. In 10% of the 9 and 12 months, extreme drought occurs at Lamas station. Neither severe nor extreme drought events are observed on the 3-month timescale at Karahacılı, Lamas, Efren and Pamuk stations. However, the percentage of these drought events increases on other timescales; this is more evident in the lower part of the sub-basins. This shows that the percentage occurrence tendency of the meteorological drought events in the study area is substantially high in the lower part of the sub-basins. Similar results related to spatial differences of SPI and SSI are obtained when a general comparison is made between the results from this study and the results of previous research covering the Seyhan and Ceyhan river basins (e.g., Sönmez et al., 2005; Gümüş and Algın, 2017; Bayer Altın et al., 2020). In terms of SPI values, the occurrence of an extreme drought event is observed in the middle and south of the eastern Mediterranean Basin; and in terms of SSI values, it is encountered in the northeast of the Seyhan and Ceyhan river basins (Gümüş and Algın, 2017).

4.2 Correlation between SPI and SSI

Since the study area is located in a semi-arid climate zone, it is of great importance to increase the sustainability of water conservation and balance of usage. Providing effective water resource management can only be achieved by identifying the occurrence of hydrological drought and by obtaining early warning information (Gümüş and Algın, 2017). Thus, the Pearson's correlation coefficients (*r* values) based on the values of SPI and SSI in the series on timescales from 1 to 24 months are shown in Figure 5a. For the 1-month and 3-month timescales, the correlation is the weakest and the coefficients vary from –0.08 to 0.18 and from –0.24 to 0.16, respectively. The correlation on the 6-month timescale is similar to that on the 3-month timescale, and is weakly positive, varying from 0.11 to 0.47. On the 9-month timescale, the correlation varies between 0.11 and 0.53. Correlation coefficient between SPI and SSI on the 12-month timescale is also similar to the value on the 9-month timescale, ranging between 0.21 and 0.54. However, for the timescale of 24 months, the correlation coefficient of the corresponding indices has a strongly positive value and varies from 0.42 to 0.79.

The SPI and SSI for Gördürüp, Kravga and Hamam stations located in the upper and middle parts have correlation coefficients of 0.79, 0.77 and 0.75 on the 24-month timescale, respectively; while for Karahacılı, Pamuk, Lamas and Efrenk stations located in the lower part, the correlation coefficients between SPI and SSI are 0.53, 0.53, 0.49 and 0.42, respectively. This suggests that the relationship between SPI and SSI is stronger for longer timescales. Findings of SPI and SSI at longer timescales can give an idea of the duration of dry periods in the basin, given that the SPI responds slower as the timescale increases and thus cycles of positive or negative SPI values become more visible. Furthermore, the period of occurrence and duration of dry years dissimilar from one station to another. Generally, the results indicate that drought events are frequent at shorter timescales but last for shorter durations at longer timescales, and droughts are less frequent but persist for longer periods. Otherwise, the SPI at longer timescales such as 12 and 24 months are suitable for representing droughts. Since these events usually take a longer time to evident as the SPI responds more slowly to short-term precipitation variation. These results are

consistent with the results of previous studies on river basins under the influence of the Mediterranean climate (Loukas and Vasiliades, 2004; Vasiliades and Loukas, 2009; Lorenzo-Lacruz et al., 2013; Ljubenkov and Kalin, 2016; Bayer Altın et al., 2020). Using the SPI and SSI analysis on 12-month and longer timescales, these researches reported that streams tend to conform to the general pattern characterized by prolonged passivity in hydrological response to meteorological drought conditions. The results related to the streamflow index that has the strongest correlation with precipitation during longer timescales (12–24 months) are detected in other Mediterranean regions and countries (Ljubenkov and Kalin, 2016; Gümüş and Algın, 2017; Boudad et al., 2018). According to Salimi et al. (2021), in the northern Iran, the high correlation coefficient between SPI and SSI for the 24-month period means that the meteorological drought in the region affects immediately the surface water. However, Lamas station has average correlation values. This indicates that the lower channel of the Lamas causes rapid flow due to the topographic features. This contrast between the upper and lower parts may be explained by two factors: natural and artificial. The natural part of the streamflow consists of precipitation from the water collection area located in the part of the Taurus Mountains, which meets moist air masses from the sea. This area corresponds to the upstream of the sub-basins, with small settlements consisting of several dwellings. The artificial factor is the result of human activity that requires excessive water consumption for agriculture, urbanization and animal husbandry in the lower part of the sub-basins. It is evident that the effects of the relief characteristics of the sub-basins and artificial factor involved in the sub-basins, influence the correlation between precipitation and streamflow indices at these stations. Therefore, correlation coefficients for watercourses can differ considerably among individual sub-basins of the eastern Mediterranean Basin. It is likely that the combination of human activities, alongside natural catchment and climate characteristics, will produce more divergent results (Barker et al., 2016).

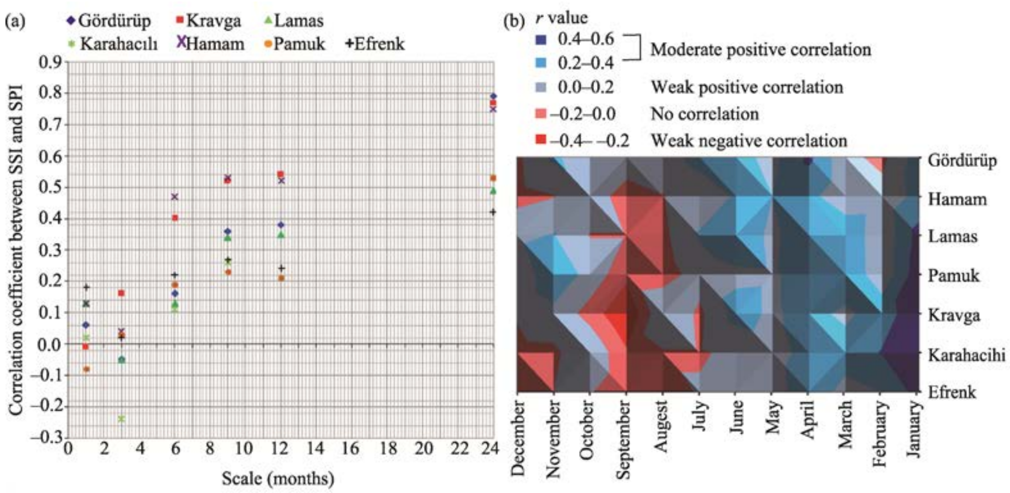

Fig. 5 Correlation coefficients between SSI and SPI for timescales of 1, 3, 6, 9, 12 and 24 months (a) and correlation coefficients between SSI and SPI for each month (b). Note that the *x*-axis in the right panel represents the 12 months of the year.

Figure 5b and Table 4 show the relationship between SPI and SSI for each month. On a monthly scale, a moderate positive correlation (0.20<r<0.50) of SPI and SSI is observed in January, the coldest month of the year at all stations except Gördürüp and Lamas. The moderate correlation is weaker during the winter months on shorter timescales. A negative correlation is encountered in September at all stations except Gördürüp. This month generally follows the summer (especially August) and autumn (October and November) months. In this case, correlations between SPI and SSI indicate seasonal differences on shorter timescales (e.g., 1 month). The correlations between SPI and SSI during winter and spring are moderate and weak

but positive. This is related to the fact that most of the precipitation falls in winter and spring between January and May and the snow melt extends from January to June, with discharges especially in March, April and May; whereas the correlations in summer and autumn are weak and negative due to low precipitation, which is prolonged from summer to the end of autumn. Thus, the lowest and negative correlation coefficient values are encountered in September at all stations, ranging between –0.11 and –0.01, representing the light brown color in Figure 5b.

Table 4 Correlation coefficients between SSI and SPI for 12 months of the year

Month	River		Gauging station				
	Gördürüp	Lamas	Kravga	Hamam	Pamuk	Efrenk	Karahacılı
January	0.29	0.26	0.47	0.52	0.50	0.54	0.48
February	–0.05	0.07	0.05	0.06	0.33	0.41	0.20
March	0.05	0.05	0.36	0.37	0.15	0.31	0.12
April	0.44	0.26	0.37	0.30	0.27	0.27	0.35
May	0.13	0.20	0.15	0.17	0.17	0.12	0.09
June	0.28	0.22	0.35	0.16	0.27	0.04	0.08
July	0.27	0.08	0.22	0.09	–0.04	–0.02	0.02
August	0.12	–0.01	–0.05	–0.10	0.20	–0.02	–0.10
September	0.15	–0.11	–0.01	–0.14	–0.40	–0.17	–0.16
October	0.06	0.13	–0.01	0.13	–0.08	0.18	0.02
November	0.24	–0.01	0.21	0.35	0.15	–0.05	0.00
December	–0.04	–0.07	0.16	0.04	0.02	–0.06	–0.17

The increase in precipitation at the end of autumn and the beginning of winter also causes an increase in streamflow. Thus, the highest and most positive correlation values are found in January, ranging between 0.26 and 0.54. As the length of the timescales increases, the correlation between precipitation and streamflow indices becomes clearer, indicating that sub-basins have a seasonal connectivity between hydrologic index and precipitation. Ljubenkov and Kalin (2016) stressed that water level has the strongest correlation (r>0.70) in the winter and spring months for a shorter timescale in Slovenia. Such information can guide water resources management by providing a more exacting evaluation of processes involved in the watershed (Farjad et al., 2016).

5 Conclusions

In this study, hydrological and meteorological droughts based on SSI and SPI using monthly precipitation and streamflow time series, respectively, were analyzed for four sub-basins in the eastern Mediterranean region of Turkey during the period from 1967 to 2017. The percentage of drought events is more pronounced in the lower part of the sub-basins at longer timescales. This indicates that the percentage occurrence trend of meteorological drought events in the study area is significantly higher in the lower part of the sub-basins. Extreme and severe values of SPI for all timescales emerge as severe and moderate hydrological drought in the following year from the end of 1990. Extreme hydrological droughts are observed after 1990–1991. Meteorological drought causes a decrease in streamflow in the following year and is reflected as hydrological drought. This is more evident since the mid-1990s at all stations. The values of SPI-12 show that extreme and severe drought events are observed in 2013–2014, while the drought events for SSI-12 are observed in the following year, i.e., 2014–2015. The correlation between SPI and SSI is stronger in the upstream environment of the sub-basins where the natural environment is preserved, than the downstream environment. There is a strong positive correlation of SPI and SSI for longer timescales (9, 12, and 24 months), while the correlation is negative and slight for shorter timescales (e.g., 3 months). The highest and most positive correlation values (0.26–0.54) are found in January; this is because the precipitation increases in the late autumn and early winter, leading to the increase of streamflow.

These results can be applied in planning the use of water resources in the eastern Mediterranean Basin to achieve better water management and sustainability. For the appropriate management of sustainable water resources, it is necessary to understand the sensitivity of the basins to drought. This is especially important in the eastern Mediterranean basin, where agriculture is the main livelihood of the population. To determine the tendencies of drought in the sub-basins of the eastern Mediterranean Basin and the impact of drought on agricultural production, the findings of this research will act as a guide for decision-makers involved in the administrative structure of the region.

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